Upgrade of the Hydrodynamic Component of the Navy's Mine Impact Burial Prediction Model (IMPACT28)

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LONG-TERM GOALS

The long-term goal is to improve the U.S. Navy's mine impact burial prediction capabilities in littoral regions through updating the Navy's existing mine impact burial models (2D with imperfect physics) such as IMPACT28 to 3D mine impact burial prediction model with full physics (IMPACT35). Development of the Navy's new model (IMPACT35) has the NPS students' (U.S. Naval officers) participation as their thesis studies that enhances the Navy's R&D program and well prepares the students with their combat effectiveness.

OBJECTIVES

- To collect and analyze the data of mine drop experiments for model development and evaluation
- To develop and verify a new noise filtering method (i.e., the rotation method) to process the data collected from the mine drop experiments
- To develop and verify a new method (i.e., the triple coordinate transform scheme) for predicting the mine movement in the water column
- To update the hydrodynamic part of IMPACT28 (two dimensional with simplified physics) to IMPACT35, a three dimensional full physics model
- To provide the analyzed data from mine drop experiments to the mine impact burial prediction modeling (IBPM) community
- To deliver the hydrodynamic part of IMPACT35 to the IBPM community
- To integrate the NPS mine impact burial prediction model into the Naval Oceanographic Office mine warfare program for operational use

APPROACH

Several approaches were taken to develop a comprehensive three dimensional mine impact burial prediction model, IMPACT35.

(A) Development of a New Scheme for Cavity (Air-Water, Water-Sediment) Calculation

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A new scheme has been developed to calculate the buoyancy and hydrodynamic forces ($\mathbf{F}_b$, $\mathbf{F}_h$) and torques ($\mathbf{M}_b$, $\mathbf{M}_h$) for a cylinder penetrating through air-water and water-sediment interfaces. At the instance when the cylinder penetrates into an interface, three situations may exist: one-side entry with the lower surface partially contacting the interface (Fig. 1a), one-side entry with partial area with the lower surface completely inside the lower medium (Fig. 1b), and two-side entry (Fig. 1c). For the two-side penetration, the upper (above the interface) and lower (below the interface) parts of the cylinder are represented by $D^{(1)}$ and $D^{(2)}$. For the one-side penetration, the upper (or lower) part of the cylinder are considered as the combination of $D^{(1)}$ [or $D^{(2)}$] and a sub-cylinder $C^{(1)}$ [or $C^{(2)}$]. In general, the upper and lower parts of the cylinder are represented by [$C^{(1)}$, $D^{(1)}$] and [$C^{(2)}$, $D^{(2)}$]. For the two-side penetration, $C^{(1)} = C^{(2)} = 0$.

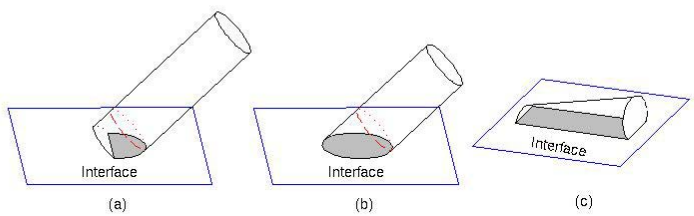

Fig. 1. (a) One-side entry with the lower surface partially contacting the interface, (b) one-side entry with partial area with the lower surface completely inside the lower medium, and (c) two-side entry.

(B) Development and Verification of a New Scheme for Modeling Mine Movement and Orientation

Triple coordinate systems are introduced to predict translation and orientation of falling mine through the water column (Chu et al., 2004a): earth-fixed coordinate (E-coordinate), cylinder's main-axis following coordinate (M-coordinate), and hydrodynamic force following coordinate (F-coordinate). Use of the triple coordinate systems and the transforms among them leads to the simplification of the dynamical system. The body and buoyancy forces and their moments are easily calculated using the E-coordinate system. The hydrodynamic forces (such as the drag and lift forces) and their moments are easily computed using the F-coordinate. The cylinder's moments of gyration are simply represented using the M-coordinate. The model has been evaluated by several mine experimental data (Chu et al., 2004d).

(C) Development and Verification of 3D IMPACT35

IMPACT35 was developed from 2D IMPACT28 with full physics and new schemes. IMPACT35 keeps all the mine types and their physical parameters as used in IMPACT28, and contains new components of hydrodynamics, new treatments of air-water and water-sediment interfaces. The model contains five types of input: (1) mine types, (2) release medium (air or water), (3) bottom type (profile of shear stress), (4) release kinematics (release angle and rotation rate), and (5) release medium parameters (release altitude, water depth, and water temperature). The output includes: temporally varying position and orientation (3D) in the air, water, and sediment phases, the bottom impact angle, and penetration depth. The computer codes will be written using Matlab with full 3D visualization capability.

(D) Model Evaluation Procedures

Since the new model (IMPACT35) contains new physics and treatments, the model evaluation includes theoretical and experimental procedures. The theoretical evaluation procedure is conducted through the peer-review process of journal articles. The experimental evaluation procedure is conducted through model-data inter-comparison.

WORK COMPLETED

The structure of the new 3D IBPM model with full physics has been constructed from the existing 2D IBPM model with reduced physics (IMPACT28). IMPACT35 has three phases (air, water, and sediment) and two interfaces (air-water, and water-sediment.

The hydrodynamic part of IMPACT35 has been developed and evaluated using the data collected from the Mine Drop Experiment (MIDEX) and Mine Burial Experiment conducted at the Naval Postgraduate School (NPS) (Chu et al., 2004d).

Triple coordinate transform method was developed and evaluated. This method is the core of the hydrodynamic part of IMPACT35. The theoretical part of the method was published in the Journal of Applied Mechanics.

The new scheme for cavities (air-water and water-sediment) has been developed.

The comparison between IMPACT35 and IMPACT28 has been conducted.

RESULTS

(1) The model physics, development, and verification of IMPACT35 were undergone thorough peer-review processes and have been published in the Journal of Applied Mechanics, Experimental and Thermal Fluid Sciences, International Journal of Bifurcation and Chaos, and Advances in Fluid Mechanics (see publication list).

(2) IMPACT35 is better than IMPACT28 using the NPS MIDEX and MIBEX data. The burial depths were compared with measured burial depth data (Fig. 2). As evident, IMPACT35 improves the prediction capability. The existing 2D model (IMPACT25) over predicts actual burial depth. However, the 3D model (IMPACT35) predicts the burial depth reasonably well. Since the gravity cores were taken for approximately two to three meters from the impact location, several cores were taken for each drop. This allowed an average to be calculated in order to yield more accurate data for each drop.

IMPACT/APPLICATIONS

• The dynamic system (nonlinear equations) for the mine movement has the potential impact on the nonlinear dynamics. The hydrodynamics of mine impact in water column can be applied to a general scientific problem of the fluid-rigid body interaction including stability and chaotic motion.

• The noise reduction scheme (rotation method) will impact the scientific and Naval mine warfare communities on the mine movement in the water column.

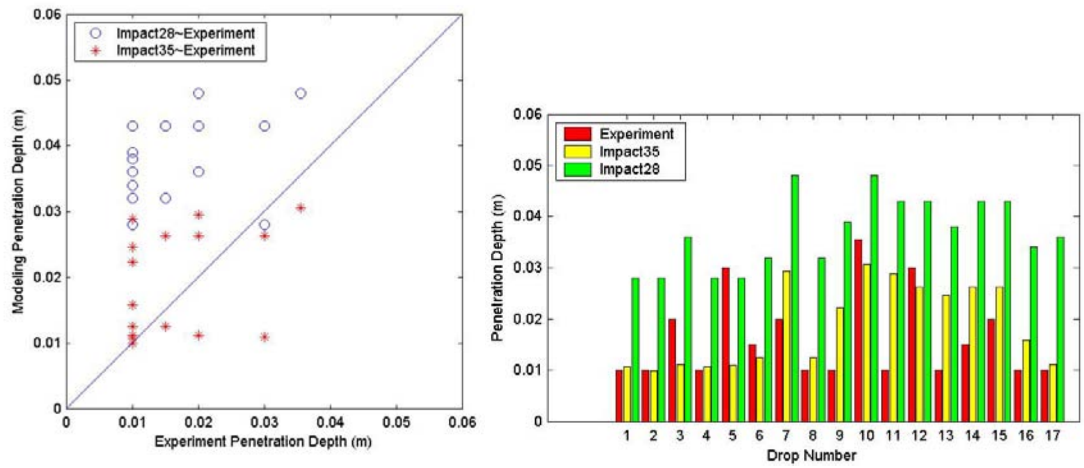

Fig. 2. Comparison between observed and predicted mine burial depths by IMPACT35 and IMPACT28.

RELATED PROJECTS

This project is related to the ONR Expert System program. The results obtained from this project are the basic materials for building the Expert System for mine burial prediction.

THESES DIRECTED:

Three students, LT Albert Armstrong, LT Michael Cornelius, LCDR Steve Mancini (all USN) are working on the project for their theses.

TRANSITIONS

• The results obtained from this project are transferred to the Naval Oceanographic Office, COMINEWARCOM, and the ONR Mine Impact Burial Prediction group such as the mine expert system and mine scour and liquifaction groups.

• The hydrodynamic component of IMPACT35 was transferred to the IBPM community such as to Drs. Alan Brandt and Sarah Rennie at the APL Lab in the John Hopkins University, Drs. Phil Valent, Andrei Abelev, and Paul Elmor at the Naval Research Lab.

• Hydrodynamic component of IMPACT35 was used for development of the Expert System for Mine Impact Burial at the Applied Physics Laboratory of the John Hopkins University and the Environmental Sciences Department of the University of Virginia.

• The datasets collected from MIDEX ($1/15^{th}$ size), NSWC-Carderock Experiment ($1/3^{rd}$ size), and Corps Christi Experiment (full size) will greatly impact on the development of an accurate Mine Impact Burial Prediction Model.

• The data were also used for development of the Mine Scouring and Liquifaction modeling effort at the Scripps Oceanographic Institution (headed by Dr. Scot Jenkins).

PUBLICATIONS

Chu, P.C., C.W. Fan, A. D. Evans, and A. Gilles, 2004a: Triple coordinate transforms for prediction of falling cylinder through the water column. Journal of Applied Mechanics, 71, 292-298.

Chu, P.C., M. D. Perry, E.L. Gottshall, and D.S. Cwalina, 2004b: Satellite data assimilation for improvement of Naval undersea capability. Marine Technology Society Journal, 38(1), 11-23.

Chu, P.C., and C.W. Fan, A. D., 2004c: Three-dimensional rigid body impact burial model (IMPACT35). Advances in Fluid Mechanics, 6, 43-52.

Chu, P.C., A. Gilles, C.W. Fan, 2004d: Experiment of falling cylinder through the water column. Experimental and Thermal Fluid Sciences, in press.

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Chu, P.C., N. Vares, and R. Keenan, 2004f: Uncertainty in acoustic mine detection due to environmental variability, DVD-ROM. Sixth Monterey International Symposium on Technology and Mine Problems, NPS, Monterey, California, May 10-14, 2004.

Chu, P.C., A. Evans, T. Gilles, T. Smith, V. Taber, 2004g: Development of Navy's 3D mine impact burial prediction model (IMPACT35), DVD-ROM. Sixth Monterey International Symposium on Technology and Mine Problems, NPS, Monterey, California, May 10-14, 2004.

Chu, P.C., S. Mancini, E. Gottshall, D. Cwalina, 2004h: Improvement of Naval undersea capability using satellite data assimilation, DVD-ROM, 72th Military Operations Research Society Symposium, NPS, Monterey, California, June 22-24, 2004.

CONFERENCE PRESENTATIONS

Chu, P.C., A. Evans, T. Gilles, T. Smith, V. Taber, Development of Navy's 3D mine impact burial prediction model (IMPACT35), Sixth Monterey International Symposium on Technology and Mine Problems, NPS, Monterey, California, May 10-14, 2004.

Chu, P.C., N. Vares, and R. Keenan, Uncertainty in acoustic mine detection due to environmental variability, Sixth Monterey International Symposium on Technology and Mine Problems, NPS, Monterey, California, May 10-14, 2004.

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